# Reserves In Western Basins

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## Introduction

Vast quantities of natural gas are entrapped within various tight formations in the Rocky Mountain area. The Reserves in Western Basins project seeks to characterize and quantify these resources and to break down the factors that will ultimately lead to exploitation and conversion of these resources into producing reserves. The ultimate goal of this project is to encourage development of these resources by the oil and gas industry through a greater understanding of the resources themselves and the technology required for their exploitation. In this way, the technical and economic risks associated with locating, drilling, completing and producing these resources at commercial rates will be facilitated.

The Reserves in Western Basins project commenced in 1991 and focused on three basins: the Greater Green River (GGRB), Piceance and Uinta (Figure 1). A subsequent project to study the Wind River Basin using the same methodology was recently awarded to The Scotia Group* (Scotia). For each study, the starting point was resource assessment work performed by the U.S. Geological Survey (USGS). The USGS resource assessments focused on establishing a geological framework and constructing probabilistic in place and recoverable resource estimates utilizing the Delphi method. Scotia's task was to firstly review these estimates and then perform a more detailed geological and engineering workup to develop criteria for estimating reserves. This work included detailed log analysis, work with cores, mapping and volumetrics, engineering analysis of drilling, completion and production data, and statistical analysis of productivity trends.

The basins studied contain a diverse variety of geological settings both structurally and via geological environments of deposition and plays display markedly differing productive characteristics, even when apparently geologically similar.

## Objectives

Encouraging the commercial development of tight gas resources is the prime objective of this study. In comparison to conventional reservoirs, tight gas reservoirs pose their own unique set of challenges. Such challenges often involve the development and application of new technologies which, particularly when newly introduced, represent a significant additional cost component.

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Due to uncertainties as to the application of such technologies, one of the prime objectives of our work has been to document where possible the technologies being used, their success in improving productivity, and their effect on the basic economics. Since there is normally a high degree of inertia involved in technology transfer and demonstration of such technologies, the basic data from our studies has been made available for public release to allow interested parties to perform their own analyses and draw their own conclusions independent of the work performed by Scotia. This data is available in digital form, including core analysis information, logs, maps and other important data.

## Approach

In order for the results of this study to be widely available, a starting premise was that it should be based entirely upon public domain data and data volunteered by companies on the basis it could be used as non-proprietary. Basic information gathered from the public domain included digital well and production data from Petroleum Information Corporation, published data and reports to state and federal government authorities, and technical reports specifically generated on the areas in question. Companies were actively sought out to volunteer additional information, particularly core analysis data and any information on reservoir pressures, a non-reported data item in the public domain for this region.

All relevant information was databased utilizing the GeoGraphix GIS software for the purpose of analysis and mapping. All production data was projected utilizing standard decline curve and Fetkovitch type curve methods to derive an estimate of ultimate recovery (EUR) for each well in the area of interest that produced from the tight sand section. Collected conventional core analysis data was databased and processed utilizing Scotia's proprietary CorePro system to provide corrections of ambient air permeability to a representative in-situ condition. This data was then utilized to calibrate a grid of wireline logs covering each basin and play and this data was processed with Scotia's proprietary SLOG system, specifically the tight gas sand module using the methods of Kukal. Comparison of log-derived parameters with productive characteristics allowed the establishment of cutoffs and eventual calculation of pay thicknesses and average reservoir properties which were used in volumetric mapping of each play. The volumetric maps were planimetered to derive gas in place and the resource was broken down by porosity/permeability range to in effect quality rate the gas in place estimates as a function of these parameters.

## Project Description

The ability to quality rate the calculated resources by porosity/permeability range was a significant breakthrough in firstly subdividing the large resource present into groups and secondly in addressing the aspect of recovery and hence reserves (Figure 2). In evaluating the recovery factor for a tight gas sand well, the biggest issues are unknowns related to the ultimate drainage area of the well. This drainage area will depend not only on the natural reservoir properties as measured, but also on the presence of natural fracturing and the effectiveness of the hydraulic fracturing treatment utilized as part of the completion process. This combination of unknowns leads to a marked lack of correlation between any one factor and the productive characteristics of the well. In other words, for a superior well to result, many factors must all be working in the same direction. A methodology was developed for statistically analyzing existing tight gas wells in each play, determining the average drainage area and range of drainage areas, and combining this with a base recovery factor over the drainage area as a function of degree of pressure depletion, and then applying an additional non-commercial fraction. This methodology, illustrated in Figure 3, resulted in a range of expected recovery factors for application at the play level.

## Results

A number of diverse and contrasting plays and geological settings occur in each of the studied basins and these were individually documented, described and analyzed. Each individual play is characterized by a specific set of geological environments of deposition, physical settings and resulting productive characteristics (Table 1). It is interesting to note that apparently similar settings have markedly different productive characteristics when comparing one basin to the next (Table 2), illustrating the fact that a combination of optimal conditions is required to provide the opportunity for the best productive characteristics.

As part of the work performed, the resource was characterized in terms of its ability to be accessed by current technology as well as its economic viability for exploitation. Table 3 summarizes this breakdown and Table 4 provides play level information. Of the total evaluated in-place resource in all three basins, 64% was determined to be *technologically non-viable* in that this resource resided in rocks with in-situ permeabilities less than 0.001 md. Such resources are termed *technologically non-viable* since they are contained in reservoirs considered too tight for commercial exploitation using today's hydraulic fracturing technology. Portions of this enormous resource will only become accessible via future cost reduction and improvement in massive hydraulic fracturing technology.

The remaining 36% of the evaluated resources are contained in reservoirs considered to have in-situ permeabilities greater than 0.001 md and are termed *technologically viable*. Of this resource, 11% is termed *non-demonstrated* since it is contained in reservoirs that have not shown to be commercially productive. *Non-demonstrated* resources commonly occur in particular facies such as alluvial or other non-marine depositional systems that are characterized by a high degree of lenticularity. New developments in well completion and stimulation technology will be required to access these resources. The remaining 25% of the evaluated resources represents what has been termed as *demonstrated* resources. These are in-place volumes that are potentially available for conversion into reserves. Of this volume, 3% of the total resources are considered to be *established* and characterized by favorable expectation in terms of recovery, drilling risk and economics. A further 8% of the total resources are considered *non-established* being characterized by less favorable expectations in terms of recovery, economics and having higher drilling cost and risk. The differentiation between *established* and *non-established* resources is based upon a drill depth criteria termed *economic basement*. *Economic basement* is a conceptual depth that depends upon drilling and completion costs, expected reserves, gas price and success ratios. Changes in these parameters will cause dynamic movement of resources from one category to the other. The remaining 14% of the total resource is considered *speculative*. *Speculative* resources are those occurring in deeply buried locations characterized by poor well control and being deeper than any established commercial production. Such volumes are inferred by extrapolation of mapping into deep basinal areas and are defined as being below deepest commercial production. *Speculative* resources have a high degree of uncertainty associated with their quantification and are thus excluded from consideration from a reserves perspective.

For resources to qualify as having the potential for eventual exploitation and hence to contribute to future reserves, several criteria must be met. Such criteria include having sufficient permeability for exploitation using today's technology, occurrence at depths where average recoveries provide an economic return at $2/Mcf gas prices, and having sufficient analog production in the play to establish meaningful expectations. The reserves that have been evaluated fall into the classification of probable, possible and potential. In the case of the latter, this term is used to indicate that such reserves are undiscovered, strictly speaking, although part of a mapped, continuous tight gas deposit. Table 5 provides a breakdown by basin and play of the evaluated reserves.

## Benefits

The work accomplished to date in the GGRB, Piceance and Uinta basins and that continuing in the Wind River Basin is providing the industry with a valuable compilation of information on the significant tight gas resources present at these locations. In addition to the generated reports, digital information is available to interested parties in order that they may construct their own analyses; and as part of this exercise, a significant amount of new data has been collected, particularly core analysis information, that is publicly available for the first time. This information is available in digital form both as original ambient analyses and as in-situ corrected data.

The studies completed to date show that while certain common points exist, each play in each basin has significant unique aspects that are the subject of individual scrutiny and are the target of specialized technology applications. Because such a diverse variety of plays exist and because operators in each area have chosen differing methodologies to conquer production problems, the works performed to date provide a valuable set of analogies for applying these techniques in other areas.

## Future Activities

Work is ongoing in the Wind River Basin utilizing similar methodologies to that used in the other three areas. This work is scheduled for completion in the fall of 1997 and will be the subject of an additional topical report and release of an extensive digital data set.


## Acknowledgments

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## References

Fouch, T.D., Schmoker, J.W., Boone, L.E., Wandrey, C.J., Crovelli, R.A., and Butler, W.A. (1994), *Non Associated Gas Resources in Low Permeability Sandstone Reservoirs, Lower Tertiary Wasatch Formation, and Upper Cretaceous Mesaverde Group, Uinta Basin, Utah*, Unpublished Report for DOE by USGS under Agency Agreement No. DE-AT21-93MC30139.

Johnson, R.C., Crovelli, R.A., Spencer, C.W., Mast, R.F (1987), *An Assessment of Gas Resources in Low-Permeability Sandstones of the Upper Cretaceous Mesaverde Group, Piceance Basin, Colorado*, USGS Open File Report 87-357.

Kukal, G.C., *A Systematic Approach for the Effective Log Analysis of Tight Gas Sands*, SPE 12851 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA May 13-15 1984 p. 209-220.

Law, B.E., Spencer, C.W., Charpentier, R.R., Crovelli, R.A., Mast, R.F., Dolton, G.D., and Wandrey, C.J. (1989), *Estimates of Gas Resources in Overpressured Low-Permeability Cretaceous and Tertiary Sandstone Reservoirs, Greater Green River Basin, Wyoming, Colorado and Utah*, Wyoming Geological Association Guidebook, Fortieth Field Conference, p. 39-61.

The Scotia Group, Inc. (1993), *Reserves in Western Basins Part I: Greater Green River Basin Topical Report*, for the Department of Energy, October 1993, 146 p.

The Scotia Group, Inc. (1995), *Reserves in Western Basins Part II: Piceance Basin Topical Report*, for the Department of Energy, October 1995, 150 p.

The Scotia Group, Inc. (1995), *Reserves in Western Basins Part III: Uinta Basin Topical Report*, for the Department of Energy, October 1995, 151 p.

## Table 1: GEOLOGICAL ENVIRONMENTS BY PLAY

| BASIN/PLAY | ENVIRONMENT OF DEPOSITION |
|---|---|
| **GREATER GREEN RIVER** | |
| Cloverly Frontier | Fluvial channels and marine shoreline |
| Almond | Coastal plain, barrier plain and marine shoreline |
| Ericson | Alluvial plain, flood plain, delta plain and marine shoreline |
| Rock Springs | Lower coastal plain, delta and shoreline |
| Blair | Submarine fan, prodelta and shelf |
| Undiff Mesaverde | |
| Lewis | Deep water low stand, submarine fan |
| Lance Fox Hills | Various, mainly lenticular |
| Fort Union | Various, high;y lenticular |
| **PICEANCE** | |
| Marine | Shoreline, shallow marine and marginal marine sands |
| Paludal | Delta plain, strandplain, marsh |
| Fluvial | Non-marine coastal plain, fluvial and paralic |
| Multipay | Fluvial and paludal |
| **UINTA** | |
| Mesa Deep | Marine, marginal marine and braidplain |
| Mesa Saturated | Marine, marginal marine and braidplain |
| Mesa Transition | Marine, marginal marine and braidplain |
| Wasatch Saturated | Alluvial to marginal lacustrine |

## Table 2: PRODUCTIVE CHARACTERISTICS BY PLAY

| BASIN/PLAY | MIN DEPTH | MAX DEPTH | # WELLS | AVG MMcf EUR/WELL | BEST MMcf EUR/WELL |
|---|---|---|---|---|---|
| **GREATER GREEN RIVER** | | | | | |
| Cloverly Frontier | 7,500 | 12,500 | 123 | 1,173 | 5,000 |
| Almond | 7,500 | 13,000 | 416 | 2,300 | 17,000 |
| Ericson | 8,000 | 11,000 | 28 | 1,000 | 8,000 |
| Rock Springs | N/A | N/A | 0 | none | N/A |
| Blair | N/A | N/A | 0 | none | N/A |
| Undiff Mesaverde | N/A | N/A | 0 | none | N/A |
| Lewis | 8,000 | 14,000 | 91 | 1,933 | 8,000 |
| Lance Fox Hills | 9,000 | 13,000 | 7 | 113 | 260 |
| Fort Union | 11,500 | 13,000 | 2 | 54 | 86 |
| **PICEANCE** | | | | | |
| Marine | 1,800 | 9,000 | 247 | 394 | 2,600 |
| Paludal | 3,000 | 8,000 | 47 | 112 | 600 |
| Fluvial | 5,500 | 6,500 | 83 | 1,140 | 4,500 |
| Multipay | 3,000 | 8,000 | 140 | 737 | 2,500 |
| **UINTA** | | | | | |
| Mesaverde | 5,000 | 10,000 | 131 | 353 | 900 |
| Wasatch | 3,000 | 8,000 | 904 | 627 | 1,900 |

"Best" well represents 95th percentile EUR

## Table 3: RESOURCE BREAKDOWN BY BASIN
## Tcf IN PLACE

| | GGRB | PICEANCE | UINTA | TOTAL | % |
|---|---|---|---|---|---|
| **Mean Resource** | **1968.0** | **307.3** | **395.5** | **2670.8** | **100** |
| **<Rechnologically Non-Viable** | **1127.0** | **254.0** | **324.8** | **1705.8** | **64** |
| **Technologically Viable** | **841.0** | **53.3** | **70.7** | **965.0** | **36** |
| **<Non-Demonstrated** | **223.0** | **8.2** | **53.1** | **284.3** | **11** |
| **Demonstrated** | **608.0** | **45.1** | **17.6** | **670.7** | **25** |
| **Established** | **68.0** | **9.4** | **3.8** | **81.2** | **3** |
| **Non-Established** | **191.0** | **14.7** | **8.6** | **214.3** | **8** |
| **Speculative** | **349.0** | **21.0** | **5.2** | **375.2** | **14** |

## Table 4: SCOTIA RESOURCE SUMMARY
## Tcf IN PLACE

| BASIN/PLAY | MEAN RESOURCE | TECH NON-VIABLE | TECH VIABLE | NON-DEMO | DEMO | SPEC | NON-ESTAB | ESTAB |
|---|---|---|---|---|---|---|---|---|
| **GREATER GREEN RIVER** | | | | | | | | |
| Cloverly Frontier | 279.0 | 33.0 | 246.0 | 0.0 | 246.0 | 223.0 | 23.0 | 0.0 |
| Almond | 228.0 | 157.0 | 71.0 | 0.0 | 71.0 | 17.0 | 14.0 | 40.0 |
| Ericson | 636.0 | 405.0 | 231.0 | 0.0 | 231.0 | 105.0 | 126.0 | 0.0 |
| Rock Springs | 102.0 | 44.0 | 58.0 | 58.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Blair | 7.0 | 2.0 | 5.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Undiff Mesaverde | 83.0 | 57.0 | 26.0 | 26.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lewis | 229.0 | 169.0 | 60.0 | 0.0 | 60.0 | 4.0 | 28.0 | 28.0 |
| Lance Fox Hills | 349.0 | 224.0 | 125.0 | 125.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fort Union | 54.0 | 34.0 | 20.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **PICEANCE** | | | | | | | | |
| Marine | 85.6 | 59.0 | 26.6 | 0.0 | 26.6 | 12.3 | 11.5 | 2.8 |
| Fluvial | 52.3 | 44.1 | 8.2 | 8.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Paludal | 141.1 | 127.9 | 13.3 | 0.0 | 13.3 | 7.6 | 0.0 | 5.7 |
| Multipay | 28.2 | 23.0 | 5.2 | 0.0 | 5.2 | 1.1 | 3.2 | 0.9 |
| **UINTA** | | | | | | | | |
| Mesa Deep | 47.8 | 40.9 | 6.9 | 6.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mesa Saturated | 200.7 | 163.0 | 37.7 | 31.1 | 6.6 | 3.7 | 2.9 | 0.0 |
| Mesa Transition | 87.1 | 68.1 | 19.0 | 13.9 | 5.1 | 1.2 | 3.9 | 0.0 |
| Wasatch Saturated | 39.7 | 35.2 | 4.5 | 1.2 | 3.3 | 0.3 | 1.6 | 1.4 |
| Wasatch Transition | 20.2 | 17.6 | 2.6 | 0.0 | 2.6 | 0.0 | 0.2 | 2.4 |
| **TOTALS** | 2669.8 | 1703.8 | 966.0 | 295.3 | 670.7 | 375.2 | 214.3 | 81.2 |

**Table 5: RESERVES BY PLAY**
**POTENTIALLY RECOVERABLE Tcf**

| BASIN/PLAY | RESERVES |
|---|---|
| **GREATER GREEN RIVER** | |
| Cloverly Frontier | 3.1 |
| Almond | 15.2 |
| Ericson | 3.5 |
| Rock Springs | 0.0 |
| Blair | 0.0 |
| Undiff Mesaverde | 0.0 |
| Lewis | 11.8 |
| Lance Fox Hills | 0.0 |
| Fort Union | 0.0 |
| | |
| **PICEANCE** | |
| Marine | 2.9 |
| Paludal | 0.0 |
| Fluvial | 1.6 |
| Multipay | 1.0 |
| | |
| **UINTA** | |
| Mesaverde | 1.8 |
| Wasatch | 1.5 |
| | |
| **TOTAL** | 42.4 |

Figure 1
Location Map

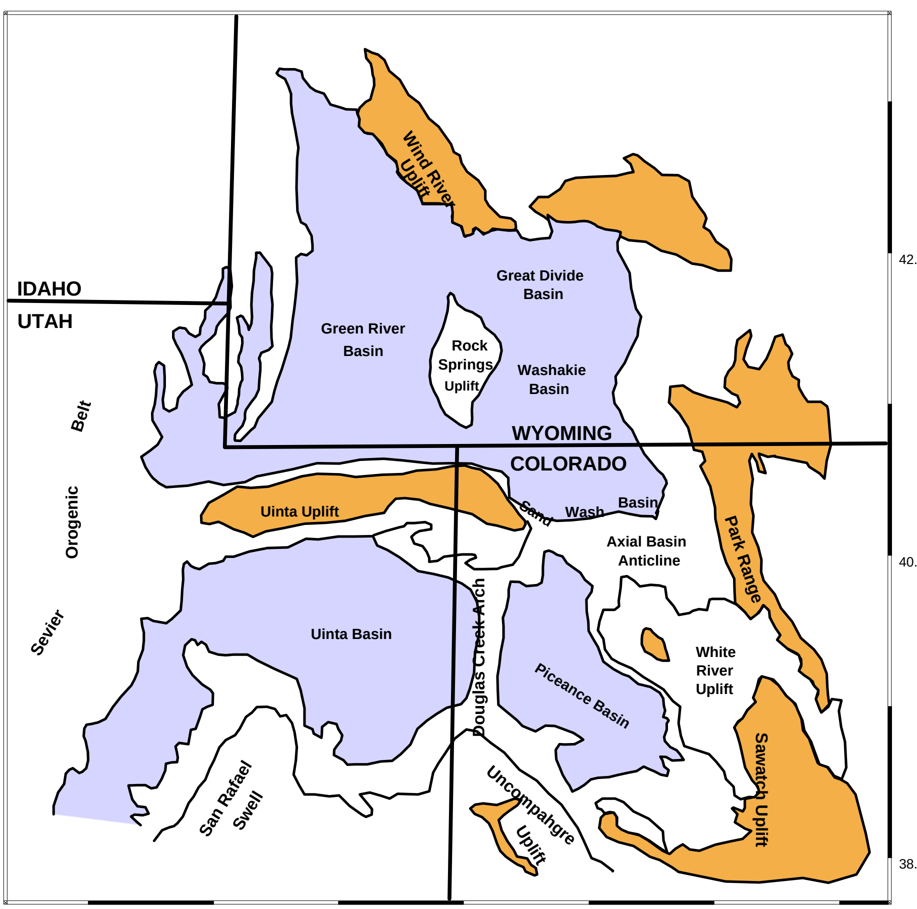


Figure 2

## Modified McKelvey Box Classification of Resources

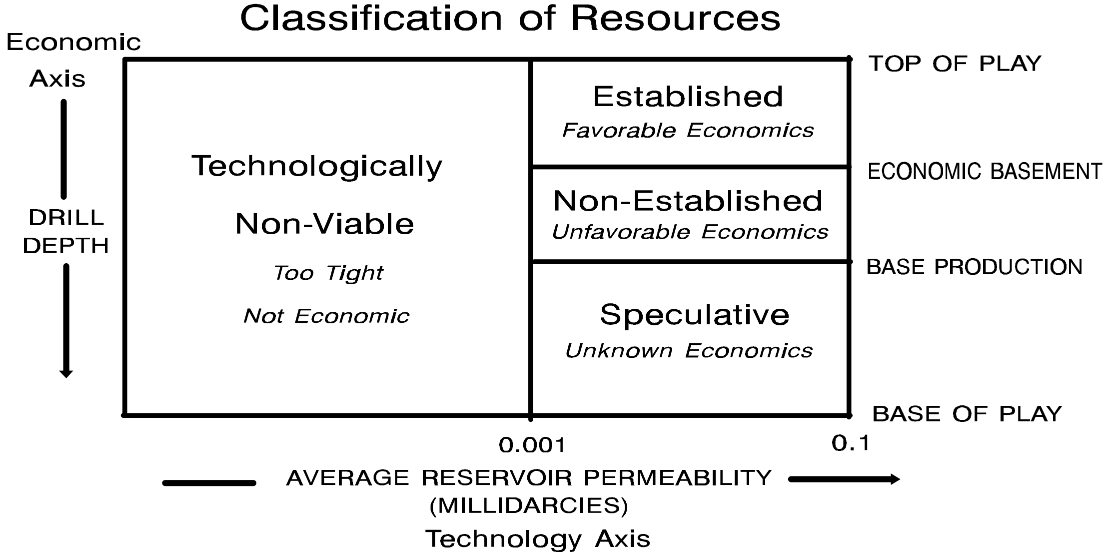
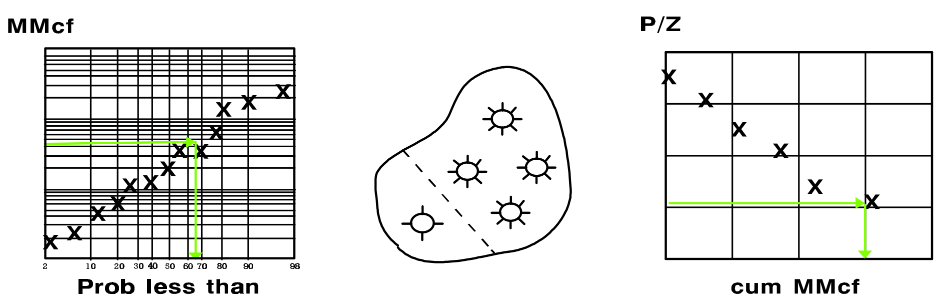



Figure 3

## RECOVERY FACTOR MODEL




**COMMERCIAL FRACTION X PRODUCTIVE FRACTION X BASE RECOVERY FRACTION = Rf**

**0.35 X 0.8 X 0.75 = 0.21**